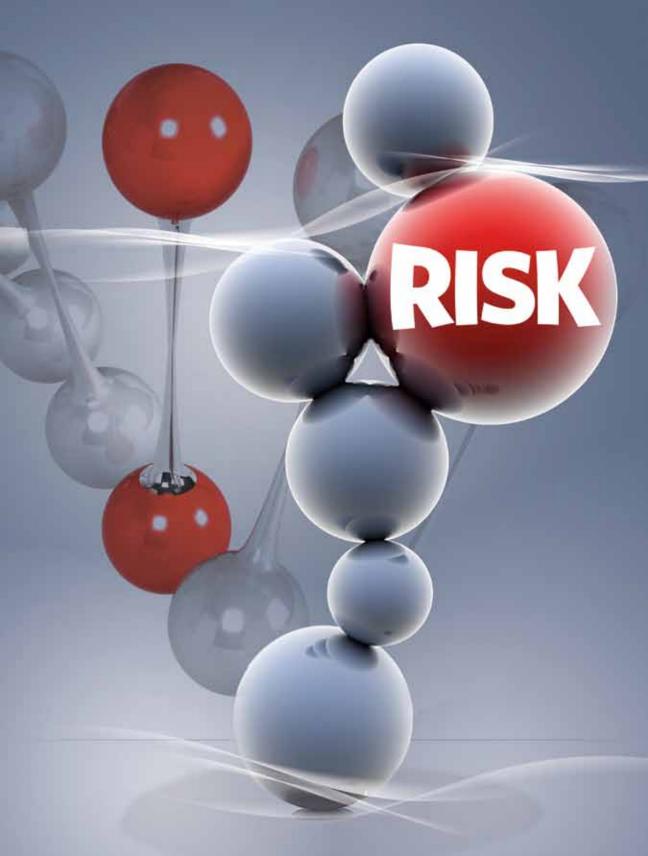# FROM AMORPHOUS TO DEFINED: BALANCING RISKS IN EVOLUTIONARY ACQUISITION

COL John T. Dillard, USA (Ret.) and David N. Ford

Incremental development entails the deliberate deferral of work to a subsequent period, using technology maturity as the measure of readiness. This article illustrates that this approach might enable more effective delivery of the first increment with a comparison of two major systems as case studies. But there are some inherent *risks* in an evolutionary approach as well, and the authors caution that certain attributes of hardware products might help determine the suitability of evolutionary development methodologies. Mutable products with costless production, continuous requirements, low maintenance, or time criticality may be more likely to reap advantages from evolutionary approaches. Products that are nearly immutable, have binary requirements for key capabilities, require man-rating, or are maintenance-intensive may not be best candidates for incremental development.

image designed by Harambee Dennis »

Risk vs. Evolutionary Acquisition

Since his work in the 1830s, Charles Darwin has received much of the credit for furthering a theory of biological evolution. While not the first to have the idea, he associated observations of species variety on the island of Galapagos with species environment, and suggested that nature selected the variations that were the fittest (Darwin, 1859). In its time (and since), the idea was considered radical and a threat to religious and social order. Mere variety itself can be controversial since, paradoxically, variety is appreciated in some domains (Ashby, 1960) and abhorred in others (Neave, 2000).

At the center of *evolutionary acquisition* are also ideas and phenomena about variety and change. As a policy for system development, it too is controversial. And as within Darwinian concepts, product evolution involves information transfer, interaction with the environment, and unpredictability of change outcomes. But unlike evolutionary biology, product variations and selections occur frequently and are non-random. Much of what we have found in the following research on evolutionary development and project management is about how managers must cope with product variety and change. Using case study analyses, review of current subject literature, and computational modeling (expounded upon in a companion article: Ford & Dillard, 2009), the focus of our research was to ascertain the program management implications of evolutionary acquisition, obtain lessons learned in past programs as applicable to future development efforts, model and simulate projects that used different acquisition approaches, derive predictions, and make recommendations to project managers for the effective and efficient harnessing and implementation of evolutionary acquisition.

Background

The Department of Defense (DoD) promulgated evolutionary acquisition (EA) as policy in 2000, and soon after, *spiral development* for the preferred acquisition strategy of all materiel (Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, 2000). EA's goal is to time-phase system requirements and provide capabilities sooner. But confusion over terms persists, despite further elaboration and even codification in statute (Armed Forces, 2002), along with a lack of full understanding of many policy implications—especially some inherent risks. DoD policy for evolutionary acquisition mandated spiral (i.e., amorphous and unplanned requirements/technologies) or incremental (i.e., defined and deferred requirements/technologies) development methodologies for all programs. Since all amorphous spirals eventually become defined increments, the disappearance of this term "spiral" in most recent (2008) policy will not be missed.

Fundamentally, EA means there will always be multiple product releases of an item. The current policy thrust is primarily about the reduction of product cycle time within an uncertain environment by using mature technology exclusively. The DoD's requirements process has also followed with "evolutionary" requirements

documents—a new idea. Uncertainty is the usual realm of program managers (PM), especially in defense systems, and is usually dealt with by seeking best information (Pich, Loch, & De Meyer, 2002). Earlier reform initiatives were aimed at overcoming information gaps and technology lag. For example, the 1990s Integrated Product and Process Development initiative was about collaboration for early and complete requirements realization. However, the current paradigm is to allow uncertainty in requirements to resolve over time and endeavor only what is immediately achievable. The Government Accountability Office (GAO) has also urged the DoD to move toward Knowledge-Based Acquisition, with Technology Readiness Levels (TRL) as the rubric for program initiation (advanced development) (GAO, 1999a). Thus, at the very heart of EA is the exclusive use of mature technology to reduce project scope.

Observations and Assessments: Implications of the Policy

We have managed and observed development efforts that employed evolutionary development approaches successfully. Two development programs of the 1990s—the Army Tactical Missile System (*ATACMS*) and the *Javelin* anti-tank missile system—were compared herein with regard to their differing acquisition strategies, TRLs, and program outcomes. Our study results support that a more effective delivery of the first increment might be facilitated with an evolutionary approach. However, the latest EA policy implications and outcomes are yet to be fully known, and some authors have already expressed insightful strategic and institutional oversight concerns (Sylvester & Ferrara, 2003). We have also described operational program management concerns about its implementation, including excessive decision bureaucracy, organizational challenges from multiple and concurrent development efforts, outmoded technology at release, funds forecasting, transaction costs, and maintenance of subsequent increment priority (Dillard, 2005). Our additional findings suggest that incremental development may not be appropriate as a one-size-fits-all strategy.

VARIETY AND COMPLEXITY

For example, variety and complexity are elements of project risk. While variety and product diversity are preferred by market consumers to satisfy mainstream and smaller niche needs, variety adds complexity in production and is costly for hardware manufacturers and owners alike. In support of EA policy, the GAO has often used product examples such as home appliances and commercial vehicles, which tend to ignore product variety from the vantage point of fleet owner vs. that of the producer (GAO, 1998a, 1998b, 1999b, 2003). The DoD is unique in that it almost entirely outsources capital projects for exclusively internal use, and this aspect of lifelong ownership of an entire

fleet of systems presents a different relationship than, for example, a product manufacturer may have with its production aircraft.

Traditional views about variety from late design changes are usually negative, except for producibility savings and performance enhancements. Changing production configurations is not viewed as efficient due to supportability issues (regarding spares and maintenance) with lot, model, and type diversity. RAND's study of support considerations for the current mixed configuration fleet of Unmanned Aerial Vehicles (UAV) reported, "Multiple aircraft configurations drive *multiple spare component packages* and, in the most extreme cases, may drive *multiple pieces of test equipment*, all significantly increasing long-term support costs" (Drew, Shaver, Lynch, Amouzegar, & Snyder, 2005; emphasis added). Reliability issues can also emerge because of insufficient testing of the changes. Depending on the degree of change, system validation and qualification become a concern if changes are not under strict control. There may be backward compatibility and interoperability issues as well. Another burden is the training impact of mixed capabilities within the force or even within the same owning and operating unit.

Higher levels of risk from system complexity are generally believed to be mitigated by control measures, as within organizational contingency theory (i.e., centralization/decentralization, etc.). The American nuclear Navy was rooted in CAPT Hyman G. Rickover's visit to Oak Ridge National Laboratory in 1946 to investigate the feasibility of using nuclear power aboard submarines. During his long tenure as head of the nuclear program, he maintained fundamental principles about technical and organizational program structures, not the least of which was personal accountability. Those who have worked with acquisition of nuclear plant materials know well both the specifications and standards of quality that are unique to this commodity, as well as Rickover's tenets of responsibility and accountability that are still in place. They are largely believed to be important aspects of how he successfully dealt with the complexities and uncertainties of a new application of technology. The *Guide to the Project Management Body of Knowledge (PMBOK)* (Project Management Institute, 2004) also asserts that change in the course of projects and products is inevitable and mandates the need for a disciplined change-control process to control its impacts—from inception to completion. Many other useful theorems on systems complexity, change, and control exist to alleviate unwanted variation in development and production.

CYCLE-TIME AND PHASE CONCURRENCY

We have observed that, though concurrency is a necessary ingredient for efficient project management, it has also long been correlated with risk (due to interdependence of activities) and might vary significantly with the types of activities underway—inferring that periods of stable production configuration between development increments reduce complexity in program structure and attendant risks. Cycle-time for the development of each increment, and the

relatively successive or concurrent phasing of the follow-on increments, will also have a definite impact on program structure, budgeting, project complexity, and organizational issues, etc. For reasons that we have brought forth in our work on the computational modeling of evolutionary development, we have concerns about the conduct of incremental development programs with continual and highly concurrent phasing of development increments.

The more projects that specialists support, the less they are proportionately available to the projects due to "queuing inefficiencies."

Particularly in matrix organization structures, as is often the case with projects, there can be a tendency to staff multiple projects with a single specialist. The more projects that specialists support, the less they are proportionately available to the projects due to "queuing inefficiencies." Their availability decreases because of the need for transition between projects (physical, mental, learning curve, etc.). This has at times resulted in large delays in project completion (Smith & Reinhartsen, 1998). Similarly, Ibrahim (2005) has shown that discontinuous enterprise membership is a contributing factor toward knowledge loss in organizations involved in large complex product development processes. Examining knowledge flows across product life cycles reveals that members often are not engaged in all phases. Whether from rotation of duties or multi-tasking, a discontinuous member's inaccurate knowledge could cause a functional error at the individual level, which is not immediately obvious at the enterprise's overall project level. Ibrahim's findings support observations of knowledge loss continuing despite investments in information technology and knowledge management.

Development Case Studies

One of the most recent monographs we found on emerging results of evolutionary acquisition is by RAND—on five immature, non-man-rated space systems. Space systems are somewhat different than general force defense projects (in their quantities produced, their operational space environment, greater proportional front-end investment, and technology development periods). RAND also found that evolutionary policy confusion persists and that EA added program complexity and uncertainty, especially with regard to budgeting. Extending their findings to non-space DoD programs, RAND highlighted the EA challenges of programmatic flux (Drew, Shaver, Lynch, Mahyar, & Snyder, 2005). They feel, and we agree, that EA presents the opportunity for typical non-space project management challenges to be even more formidable.

For such traditional defense systems, as expository cases of evolutionary acquisition, we analyzed two tactical missile programs that illustrate both planned and unplanned change: the Army Tactical Missile System (ATACMS) and the Javelin Anti-Tank Weapon System (Dillard & Ford, 2007). Both of these systems began as Defense Advanced Research Projects Agency (DARPA) programs in the 1980s and were fielded to forces and employed in combat in the 1990/2000s. See the full report at http://www.acquisitionresearch. net/_files/FY2007/NPS-AM-07-002.pdf for a detailed description of these case studies and our use of them to investigate evolutionary acquisition with computational modeling.

ATACMS employed both incremental and spiral strategies for product development, benefiting from an elegant, modular independent architecture. This program was able to omit its technology development phase by employing mature technologies for a leap-ahead capability in range. The basic system arrived essentially on budget and schedule, with several successive variants, both pre-planned and unplanned. Years later, one instance of a minor production change (uncontrolled variety) caused missile failure and a costly refit of already-produced missiles.

In contrast, Javelin used the single-step-to-full-capability approach for product development. With much greater modular interdependence, the program embarked upon advanced development with immature technologies in several critical areas—causing significant cost and schedule overruns. The system has also experienced subsequent design changes and product variety, but they have consisted more as running production changes than as product variants or blocks.

A comparison of the development and use of technology in the ATACMS and Javelin projects clearly illustrates the impacts of technology maturity on first increment project performance. The Table compares the technology maturity in the ATACMS and Javelin projects by identifying the Critical Technologies for seven subsystem categories that both products employed. For each subsystem, the Technology Readiness Level of the critical technology used at the time of insertion into the development is shown. The ATACMS project used only critical technologies with a minimum TRL of 6 and an average of 8.1. In sharp contrast, the Javelin project used technologies with a maximum maturity of TRL6 and an average of TRL5. The ATACMS project used significantly more mature technology than the Javelin project and reaped the rewards of program success.

The relative cost and schedule performance of the ATACMS and Javelin projects reflects the differences in the use of technology. The ATACMS project had no Advanced Development Phase Contract Cost Growth and only 6 percent schedule growth in the Advanced Development Phase. But the Javelin project experienced over 150 percent cost growth and 50 percent schedule growth in Advanced Development. The poorer project performance when less-than-mature technology was used supports the potential effectiveness of EA in managing technology risk.

TABLE. COMPARISON OF PROGRAMS USING DIFFERENT DEVELOPMENT APPROACHES AND TECHNOLOGY READINESS LEVELS

Key Program Characteristics - First Increment of Capability

Program Aspects	ATACMS (Evolutionary)		Javelin (Single-Step)	
DARPA Predecessor	Assault Breaker 1977-82		Tank Breaker 1981-82	
Ultimate Capability	*"Deep Attack"*		*"Fire and Forget"*	
Subsystem	**Critical Technology**	**TRL**	**Critical Technology**	**TRL**
Munition	Lance M74 Bomblet	9	Tandem Shaped Charges	5
Propulsion	Solid Rocket Motor	9	Two-Staged Solid Rocket Motor	5
Flight Control	Fin Surfaces	9	Fin + Thrust Vector Control Vanes	6
Guidance and Control	Inertial	9	Tracker Software Algorithm	4
Safe/Arm Fusing	Mechanical	7	Electronic	4
Software Function (Target Acquisition, Fire Control, etc.)	Various	6	Various	6
Sensor	N/A	-	Focal Plane Array	5
Cost of Development	~$700M		~$700M	
Contract Type	Fixed Price		Cost Reimbursable	

Tech Development Phase	0 Months	27 Months
Advanced Development Phase—Planned	48 Months	36 Months
Advanced Development Phase—Actual	51 Months	54 Months

Total Time in Development	51 Months	81 Months
Advanced Development Phase Schedule Growth	6%	50%
Advanced Development Phase Contract Cost Growth	0%	150%

Synthesis of these cases reveals that as an approach oriented primarily on the reduction of product cycle-time, evolutionary development is highly facilitated by the leveraging of mature technologies. Also, system mutability, along with other factors discussed in the next section—such as time criticality (user risk) and modular interdependency—can bolster incremental development suitability. For ATACMS, an "open," or at least elegant, architecture was fundamental for modular variety, and thorough design specification and configuration management accountability proved essential for managing the complexity of multiple product releases. In the case of the Javelin, key capabilities depended upon immature technologies and at least one binary requirement, to the detriment of project cost and schedule outcomes. In stark contrast, modular interdependence was manifested by an almost total system redesign for lengthy and costly weight reductions.

Do Product Attributes Affect Evolutionary Applicability and Outcomes?

More questions about EA include whether products with different attributes (e.g., hardware vs. software, buildings vs. electronics) may lend themselves more or less to the use of an incremental development approach. From the literature and cases we examined, we offer the following other product attributes for PMs' careful consideration when planning product capability increments.

MUTABILITY

Perhaps our foremost reservation is the appropriateness of the evolutionary development process for all project sizes and product commodities in toto, and the application of the spiral process to hardware products vs. Dr. Barry Boehm's (1985) original and most relevant application of this development approach toward software. Boehm himself warned of "hazardously distinct" spiral model imitations, and in his own words described his vision of the spiral process:

> The spiral development model is a risk-driven process model generator. It is used to guide multi-stakeholder concurrent engineering of software-intensive systems. It has two main distinguishing features. One is a cyclic approach for incrementally growing a system's degree of definition and implementation while decreasing its degree of risk. The other is a set of anchor point milestones for ensuring stakeholder commitment to feasible and mutually satisfactory system solutions (Boehm & Hansen, 2000, p. 3).

Clearly, the conceiver of this spiral notion was oriented upon amorphous requirements and continuous stakeholder inputs for the alleviation of project risk with a very mutable product (Boehm, 1988). The nature of software being

in the digital rather than physical realm, it is particularly conducive to rapid and successive revision and nearly costless production. And, Boehm encourages varying from the spiral model as needed and reverting to a sequential model if requirements are well established and the project less risky.

Multiple product increments do not often appear in large, static, singular projects such as bridges, highways, office buildings, or in other project areas that have typically long lead times or product cycles, such as feature-length films, pharmaceuticals, etc. These are what we call nearly immutable products and are much different than smaller projects (like rapid software application development) with much shorter development periods. However, as with almost everything engineered that we can observe in the physical world, even these things can evolve and change with additions, spin-offs, sequels (and prequels), expansions, etc. Mutability simplifies change, and that idea can be extended to many DoD projects.

USER RISK/SAFETY

For DoD, product attributes that are aligned with Boehm's notion of process models being driven by risk are those of mission or time criticality, survivability, and user safety. System safety is often described in terms of "man-rating" as approval for safe usage.

Time-critical or enhanced survivability systems. DoD's products have expanded risk considerations beyond Boehm's models of commercial software. Extending the idea of project risk-as-a-driver down to the level of the end user, it might seem logical to assume that time criticality of the need or mission (in which risk of not achieving project success actually endangers customer lives), might be a significant factor in the appropriate application of the evolutionary process for reduced initial product cycle-time. Perhaps defensive systems are a good example. The immediate need for a Rocket-Propelled Grenade defeater or an Improvised Explosive Device neutralizer for currently deployed forces in Iraq and Afghanistan, for example, clearly dictates that lives will be lost if a near-term capability is not achieved. We also cite as an example the National Missile Defense initiative in which, given the view of near-term threats, early deployment of even rudimentary capability has been deemed preferable to waiting for full capability. Such urgency likely precludes full and certain requirements specificity.

Non-man-rated and man-rated systems. In the same vein, non-man-rated systems (i.e., UAVs or cave-exploring robots—capabilities in which operator lives are not at risk if the product fails)—may also lend themselves readily to rapid innovation and riskless experimentation cycles. However, user hazard levels for man-rated systems may be an entirely different matter.

Man-rated systems present a different challenge. Configuration variety adds technical complexity with sometimes unpredictable interactions. In such projects as pharmaceuticals, aviation, vehicular transportation, etc., producers mitigate safety risks with thorough analyses, documentation reviews, validation testing, and other control and verification processes. By their very nature—with lethal hazards for the end user and typically lengthy approval criteria—these may not be good candidates for an evolutionary approach.

LOGISTICAL SUPPORT PLANNED DURING SERVICE/SHELF LIFE

Our observations warn that multiple configurations of hardware products come at a cost for fleet ownership. Veterans of new system deployments across the force/fleet, or throughout any large using organization, know the difficulties of rolling out a configuration change. Benefits of standardization have long been offered via production economies of scale, commonality of parts across platforms, and interoperability. If the ultimate goal is to have standardization across the DoD's force, owning multiple configurations (variety) of a system seems in opposition, with added complexity in training and supply support of the item. The logistical maintenance strategy cannot be ignored—whether the end-item is maintenance-intensive, such as tactical vehicles, or maintenance-free, such as with many electronics items and munitions, and situations in which physical changes are completely transparent to the user. For multiple-product configurations, the acquisition approach could have a huge effect on the total costs of ownership, as previously mentioned by Drew et al. (2005) in regard to UAVs.

RANGE OF REQUIREMENT ATTAINMENT

Most requirements are "continuous," i.e., may be satisfied in varying amounts of attainment. Thus, ranges of their satisfaction can be flexibly specified, allowing for thresholds (minimum values of attainment) and objectives (optimal values of attainment). Examples are range, accuracy, weight, reliability, etc. However, we have found that some requirements, often critical ones, are more binary in nature than continuous. They have a much narrower range of attainment, such that they are essentially pass/fail or go/no-go in their demonstration. Examples are Windows-compatibility, "soft" missile launch, network security, physical fit, leak-proof, shock-/vibration-/drop-proof, survivability, horizontal-to-vertical flight transition, etc. If one of these more binary-type requirements happens to be a Key Performance Parameter, its attainment will be on the project's critical path and highly dependent upon technical maturity. As such, it might practically dictate the length of the entire advanced development effort and make division into capability increments less beneficial as a development strategy. Though somewhat correlated with product reliability, these kinds of requirements demand a system that "either works or it doesn't" without the flexibility afforded by objectives and thresholds.

AMOUNT OF CHANGE—AND THE LURE OF MODULARITY

We subscribe to the current systems theorists' view that complexity is comprised of numbers (of components), connections (interdependencies) and distinctions (variety). Distinction corresponds to variety, to heterogeneity, and to the fact that different parts of complex systems behave differently (Heylighen, 1997). Variety is a component of Nobel Prize winner Herbert Simon's explanation of complexity—many different parts with many interactions. Simon argued, from his observation of complexity in things both natural and artificial, that complex systems evolve from simple systems. And, they do so more rapidly when there are stable, intermediate forms or sub-systems (like modules or "units of action") (Simon, 1981). Moreover, he argues the resulting evolution into the complex system will be hierarchical. Earlier, in *The Architecture of Complexity*, Simon (1962) proposed hierarchy as a universal principle of complex structures. He felt that complex problems could be solved more easily when decomposed into sub-problems (similar to how project managers employ Work Breakdown Structures via the Systems Engineering Process). And, sub-problem solutions could be combined into a solution for larger problems, etc.

Commonly seen today are modular industrial products that are sometimes designed as complete architectures, with standardized interfaces that invite others to introduce complementary products for insertion (Agre, 2003). The Modular Open Systems Approach (MOSA) is a relatively new DoD initiative that encourages the use of widely supported commercial interface standards and disciplined interface controls to develop systems architectures using modular design concepts (DoD Open Systems Joint Task Force, 2004).

As in biological evolution, improved "fitness" with a system's environment is sought in the adapting or evolving of systems. But others have noted that Simon's metaphors for dynamic complex systems, useful as they are for understanding complexity, fall short of explaining their evolution. While the concept of modularity suggests approximately independent subsystems may be modified or adapted as such, it has been shown that, in the aggregate, there is yet quantifiable modular interdependency that affects evolvability (Watson & Pollack, 2005). In other words, how changes in the state of one module affect the state of another is relative and measurable. Thus, Simon's writings illustrate that modularity is beneficial for production but not necessarily for evolution.

Examples of modular interdependency are plentiful. In the aircraft or automotive realm, an engine upgrade would intuitively seem to be a relatively independent subsystem change. But, systems engineers know that changes propagate through hardware almost as much as software in the long run—just as the eventual rise in building temperature from the thermostat adjustment in one modular room. For instance, adding increased armor protection (and weight) for deployed High Mobility Multi-purpose Wheeled Vehicles has resulted in increased wear-out of drive train and suspension components and impacts to vehicle range, mobility, mileage, etc. As a result, "up armor" kits have become only a stopgap measure until totally redesigned systems can be produced.

Thus, we suggest it is not only the structural modularity and standard interfaces that enable system evolution; but, it is also the relative interdependency of the modules. In short, PMs need to be mindful of the degree of change in subsequent increments/spirals. One subsystem is likely to affect another in the short- or long-run. And, that can make product evolution problematic. As Norman Augustine once said, "No change is a small change"; to convey that independent subsystems, even redundant ones, aren't always independent (Augustine, 1997).

PRODUCTION QUANTITY

Many might correlate the applicability of evolutionary development with long production runs. But we have also collaborated with officials from NASA who have said, "No two identical spacecraft are the same," which seems to contradict any idea that like configurations are a necessity among small production lot sizes (Roy, 2006). Indeed, naval shipbuilders voice the same about variation among individual ships, or within flights, of the same class. And even one-of-a-kind, nearly immutable projects like skyscrapers and bridges can be later remodeled and refitted, as discussed earlier. Aside from truly singular efforts, we have not yet found any universal evidence of an evolutionary approach being more or less suitable according to quantity of systems produced.

Recommendations for Practice

Project managers need to be aware of the inherent risks of evolutionary development and take necessary precautions to balance those risks. Many tools and control measures are developed and available to assist project managers in balancing the risks, such as TRLs, technical performance measurement, technical reviews, modeling and simulation, real options, project phasing, risk management, configuration management, earned value management, and organizational design.

Incremental development projects require steps to alleviate risks that may be inherent in the program structure. These include decisions about the number and concurrency of development increments and their scope and impact on the organization staffing.

Product attributes may help determine the suitability of evolutionary development. PMs should consider characteristics such as: mutability, time criticality, man-rating, modular interdependency, key parameters of capability vs. range of requirement attainment (i.e., binary vs. continuous), and the relative amounts of modular interdependency in the system architecture.

Rigorous configuration management accountability must be assigned and maintained for supportability, reliability, failure mode identification and causality, and to prevent the variety generated by EA from reducing total product performance.

Conclusions

Dr. Barry Boehm's recent book (2004) on software development advocates balancing disciplined (more rigid) and agile (more flexible) methods to capitalize on the benefits of both. Discipline is needed as a control mechanism to avoid risk, but agility is needed to respond quickly to customer needs. Saying, "One size fits all is a myth," he advocates a balanced approach based upon risk. Consistent with our findings, he also advocates more disciplined, risk-averse approaches for projects that are mission/safety critical, larger in size, and have more stable requirements.

It could be summarized that evolutionary development was at its inception, and is at its extension, all about risk. Paradoxically, it is an agile method envisioned to reduce risk and yet can potentially add its own. On the one hand, a spiral or incremental approach allays risk by reducing scope to render only the highest priority capabilities with the exclusive use of mature technology; and obtains early and continuous feedback from the environment for follow-on developments. On the other hand, it introduces concurrency during advanced development and adds variety in production, with all their attendant management challenges.

We have suggested that a one-size-fits-all methodology for DoD system development may not be appropriate, and we have offered for consideration several product attributes that might help determine the applicability of agile approaches. We speculate that evolutionary development may serve better than single-step development for initial capability when products are mutable, time-critical, non-maintenance-intensive, and have continuous (vs. binary) or uncertain requirements, short cycle-times (less knock-on effects), sequentially phased development blocks, and modular independence. In contrast, evolutionary development may not be as suitable when there are product safety or man-rating concerns and attributes opposite to those discussed here. In particular, PMs should understand the nature of their product requirements with regard to their range of attainment and relative to key parameters of capability and vis-à-vis the readiness level of their enabling technologies. Some key features may indeed be binary, and others may have significant ramifications of partial attainment—such as propagated change across the entire product componentry (as in weight reduction) vs. a more independent modular modification.

Variety can be both an asset (for end-users) and a liability (for manufacturers, owners, and supporters). As such, to compensate for product variety risk, we posit that acquirers must "own" the design and emphasize configuration management, keeping or assigning responsibility for that function and maintaining accountability for it (i.e., explanation of how assigned functions are being met).

Our title—"from amorphous to defined"—alludes not only to product specification, but also to risk realization in evolutionary development. PMs must be aware it has inherent challenges, both strategic and tactical; they

must balance them with tools that we have mentioned. In this article, we have both highlighted and illustrated them, as well as showing that incremental and spiral development can indeed work well—especially for technically mature and mutable products with open or elegant architecture.

Finally, stability is the quest in all things programmatic: for funding, requirements, design, production configuration, etc. But in an unstable world, and with the future filled with uncertainty, the only constant is likely to be change, and tension between control and change is probably unending. PMs do have some tools for coping, and being forewarned is forearmed. Successful use of these tools to balance control and risk in projects with a high rate of change and concurrency is an area for further research, to improve both our understanding and use of evolutionary acquisition.

Author Biographies

COL John T. Dillard, USA (Ret.), managed major weapons development efforts for most of his 26-year career in the military. He is now a senior lecturer with the Graduate School of Business and Public Policy at the U.S. Naval Postgraduate School in Monterey, California. COL Dillard is also a 1988 graduate of the Defense Systems Management College.

(E-mail address: jtdillard@nps.edu)

Dr. David N. Ford is an associate professor in the Zachry Department of Civil Engineering, Texas A&M University. In addition to teaching, he researches development project strategy, processes, and resource management. Dr. Ford earned his doctorate from Massachusetts Institute of Technology and his master's and bachelor's degrees from Tulane University. He has over 14 years of engineering and project management experience in industry and government.

(E-mail address: DavidFord@tamu.edu)

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